

Factors influencing the articular eminence of the temporomandibular joint (Review)

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Abstract. The temporomandibular joint (TMJ), the most complex and evolved joint in humans, presents two articular surfaces: the condyle of the mandible and the articular eminence (AE) of the temporal bone. AE is the anterior root of the zygomatic process of the temporal bone and has an anterior and a posterior slope, the latter being also known as the articular surface. AE is utterly important in the biomechanics of the TMJ, as the mandibular condyle slides along the posterior slope of the AE while the mandible moves. The aim of this review was to assess significant factors influencing the inclination of the AE, especially modifications caused by aging, biological sex or edentulism. Studies have reported variations in the angles of the slopes of the AE between medieval and recent human dry skulls, as well as between subjects of different racial origin. Recent articles have emphasized the significant role that tooth loss has on the flattening of the AE. Although some papers have described biological sex or age as factors which could be associated with differences in AE angulations, edentulism seems to be a significant factor impacting on the inclination of the AE.

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5. Biological sex
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1. Introduction

The temporomandibular joint (TMJ), the most complex and evolved joint in humans, is defined by the paired joints that connect the mandible to the skull, while its name is derived from the two bones that form the joint: the temporal bone and the mandible. A multitude of human mandibular movements are possible due to the TMJ, adapting the human being to omnivorous eating and making possible a wide variety of physiological functions: chewing, swallowing, speaking and even facial expression (1-3). More specific, the TMJ consists of the condylar process of the mandible penetrating into the mandibular fossa of the temporal bone, while the articular disk lays bilaterally between the fossa and the condyle (4,5).

In terms of function, the TMJ allows maximal free motion (it is a diarthrosis) (2,6), but also permits both hinging and gliding movements of the mandible within the three planes of space (7). Therefore, as the TMJ is considered a bicondylar diarthrosis, the two articular surfaces are represented by the condyle of the mandible and the bony eminence on the temporal bone (the articular tubercle or the articular eminence (AE) of the temporal bone) (2,6).

In terms of morphology, TMJ is a synovial joint as it has synovial cavity filled with synovial fluid (5). The main characteristic which differentiates TMJ from other synovial joints is that the TMJ has joint surfaces covered by dense fibrocartilage instead of hyaline cartilage, the former being considered to heal much better than the latter (8-10).

The AE of the temporal bone is an important anatomical structure in the biomechanics of the TMJ and determines the path and type of condylar-disk complex movement (11-13). AE is represented by the anterior root of the zygomatic process of the temporal bone; it has a convex shape in relation

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to the sagittal plane and a slightly concave shape in relation to the transverse plane. Two slopes have been described for the AE: the anterior slope (the non-articular slope) and the posterior slope (the articular slope, also known as the articular surface), the latter being covered by fibrocartilage. Of uttermost importance is the fact that the condylar process slides forward and downward along the posterior slope of the AE as the mandible moves anteriorly (7,13,14). The inclination of the path traversed by the condyle in relation to the AE during a protrusive or a contralateral mandibular movement is known as the condylar path/condylar guidance (15-18). The inclination of the condylar path is considered of paramount importance in the oral rehabilitation of any patient (17), while an analogue of the condylar guidance on a dental articulator is necessary in prosthodontics (18). Therefore, the anatomic slopes of AE are represented in the articulator as the horizontal condylar inclination (19). Widman even described an inverse relationship between the angle of the AE and the occlusal and mandibular planes and stated that the Frankfort horizontal plane-AE angle may be useful in orthodontic treatment (20). As the inclination of the AE dictates the trajectory of the condyle (13), modifications in the AE angulation might result in biomechanical variations of the TMJ (7,21). The particular morphological patterns encountered at bone levels may predispose to affections or complications (22). Furthermore, quite importantly, the AE is exposed to masticatory loads and forces (23). Thus, the AE reflects the changing mechanical loading environment and it develops/remodels its shape to minimize joint loads (24-29). Recently, the morphology of the AE was also found to be associated with facial profile and related to specific facial types as a survey of cone beam computed tomography (CBCT) examinations on 76 patients determined significantly greater values of the height of the AE in brachycephaly (30). Statistically significant increased AE height was observed in the TMJ of male and female participants with brachycephalic profiles as compared with individuals with dolichocephaly (30).

It is a well-known fact that movements in the TMJ are guided by the shape of bones, muscles, ligaments and dental occlusion. AE is a part of the temporal bone on which the condylar process slides during mandibular movements (13). Therefore, AE determines the path and type of condylar-disk complex movement (11-13). As AE is an important anatomical structure in the biomechanics of the TMJ, influencing the mandibular movements in humans, it is important to assess the factors which generate variations in the morphology of the AE. Different factors have been described in the scientific literature as modifying the angulation of the AE. The aim of this review was to describe significant factors influencing the anatomy of the AE, especially variations caused by aging, biological sex or loss of teeth.

2. Data collection

Data gathering was performed on medical literature articles from Clarivate Analytics/ISI Thomson Web of Knowledge and PubMed databases. The following keywords were used: 'articular eminence' and 'temporomandibular joint'. Any type of article, review or experimental study was included in the analysis. Only full text papers written in English were selected.

Some of the references of the initially retrieved articles were further analyzed and added to this research. Published articles on the AE of the TMJ, but also on TMJ morphology or TMJ function were selected. Gathering of data was improved with relevant information from three books on TMJ anatomy, TMJ disorders or dental occlusion. Therefore, the gathered data included a comprehensive collection of scientific papers from 1950 to 2020. Furthermore, observations collected from the scientific literature were supplemented with data obtained through authors' personal research.

3. The inclination of the articular eminence

The height of the articular eminence (AEH) and the inclination of the articular eminence (AEI) adjust the pathways of the TMJ condyle-disk complex, leading the way the mandible moves (14,31-37). The inclination of the AE is appreciated in relation to the Frankfort horizontal plane (12) and it influences the path of condylar movement and the degree of rotation of the disk over the condyle (12,13,33).

Examinations on human dried skulls have revealed that the AEI develops rapidly and is almost (90-94%) completed around 20 years of age (12). The AEI increases by approximately 1° (38), 1.2°-1.3° (14) each year, reaching morphological maturity earlier than the mandibular condyle (24). The AEI shows great individual differences and a wide variety of AEI values has been described in the medical literature, ranging between 30° and 94° (39).

Naturally, there are small variations between the AEI on the left and on the right sides, but no statistically significant difference has been found between right-left AEI in medieval and contemporary Croatian population (31). Yet, other researchers examining 20th century African-American and European-American dry skulls observed that right-left symmetry of AEI angles was present in only 10% of the cases (40). In addition, a significant steepness of the right AE slopes compared with the left AE angulations was also observed (40). Therefore, Jasinevicius *et al* concluded that right-left asymmetry of the AE slope angles should be considered normal (40). In addition, Zabarović *et al* after assessing the AEI on 137 dry human skulls, concluded that the asymmetry between the right and left joints seems to be almost a rule (39).

4. Factors influencing the inclination of the articular eminence

Data from medical literature have shown that AEI seems to be influenced by a variety of factors: sex, facial profile, degenerative bone disease, condyle shape, altered condylar position, increasing functional stress on the dentition (30,41-44). The temporal bone component of the TMJ undergoes a remodeling process throughout the whole life (43,45). Increased angulations of the AE have been found in male patients with brachycephaly (30) or in patients with angled condyles (44). Similarly, decreased values of the AEI were encountered in patients with flat or convex condyle or with two or more bone diseases affecting the condyle (44). Interestingly, Rabelo *et al* found an association between higher mean values of the AEI (and AEH) and box-shaped eminences (46).

Studies on human dry skulls have concluded that the values of AEI vary between medieval and recent humans (11,31). Therefore, the mean values of the AEI were statistically significant lower in medieval skulls (11,31) probably as a consequence of the different masticatory loads determined by the medieval eating habits (31). However, in another report on 60 human dry skulls specimens, no statistically significant differences regarding the AE (AEI and AEH) were encountered between medieval and contemporary Croatian populations (1). In addition, another paper reported variations between the African-Americans and European-Americans regarding the angles of the slopes of the AE (47). Thus, statistically significant steeper left central and left medial angles of the AE were encountered in European-American dry skulls of males compared to human dry skulls of males of African-American origin (47).

5. Biological sex

Several articles have concluded that the AEI and AEH vary in the TMJ of subjects of different biological sex (23,30,48-51). Thus, in a survey on 105 patients, higher mean values of AEI and AEH were measured on CBCT images of males (48). Similarly, Zabarović *et al* found significantly steeper AEI in both dentate and edentulous dry skull male specimens (39). Moreover, results of another research group showed greater values of AE angulation in males with brachycephaly (30). Moreover, other observations on AEI have indicated elevated values in males over 60 years of age (44). Furthermore, a recent paper stated that completely edentulous men displayed higher AEI values as compared with completely edentulous female patients (23). However, Unal Erzurumlu and Celenk described no statistically significant difference between the AEI values of dentate females and males (23). Moreover, in a 2016 study, no statistically significant differences regarding AEI and AEH were encountered between medieval and contemporary Croatian populations independent of age and sex (1). Additionally, Jasinevicius *et al* reported in two studies no differences in AE angulation between the sexes (47,52). Interestingly, there are also studies describing elevated AEI values in males than in females, but the measured differences were not statistically significant (13,49). Thus, Sümbüllü *et al* determined higher AEI and AEH values in men with or without TMJ dysfunction than in women, but the values did not vary with statistical significance (13). Likewise, Chiang *et al* presented higher, but not statistically significant higher, values of the AEI in the case of men with unilateral posterior missing teeth as compared to women having the same type of edentulism (49).

6. Age

An interesting relationship of the AEI with patient age is discussed in the medical literature. A 2012 analysis of 93 CBCT images concluded that the AEI presents the highest values in young adults between 21 and 30 years of age, consequently decreasing after the age of 31 in patients with no TMJ dysfunction (13). However, a 2017 research found no difference in the mean AEI values of patients from different age groups (44). Furthermore, other evaluations on more than 100

skulls reported also no association between AEI measurements and age (47,52). Interestingly enough, it was also published that there could be a correlation between flattening of the AE and a subject's age (53), but complete edentulism leads to accentuated flattening of the posterior slope of the AE than physiological changes caused by age (53). Plus, a recent paper reported no statistically significant differences in the angulation values of the posterior slope of the AE between participants of different ages which presented maintained occlusal support zones at the time of the study (54). After analyzing 170 orthopantomograms, Oruba *et al* did not confirm a correlation between AEI and age (54). As no significant AEI modifications were described in older people with at least one occlusal support zone per side, Oruba *et al* concluded that ageing seems not to influence AEI when occlusal support zones are present (54). Hence, alterations in the morphology of the AE such as flattening of the posterior slope of the AE have been associated more with missing teeth/loss of occlusal support zones than with the physiological processes of ageing in itself, which is normally taking place in the TMJ of older patients (53,54).

7. Edentulism

Edentulism may cause modifications in the masticatory biomechanics, which may lead consequently to changes in the AE (23,32,49,53,54). Several research groups described finding reduced AEI values in edentate patients compared to dentate ones (23,32,49,53,54). Recently, an analysis of the effects of edentulism on the TMJ determined lower mean AEI in orthopantomograms of edentulous subjects compared to panoramic radiographs of dentate participants in the study (23). As well, results of another 2020 radiological study indicated a major diminution of AEI in the elderly (>60 years of age) with no dental occlusion (54). Important flattening of the AE was observed in older individuals with loss of all occlusal support zones in contrast to elderly in which at least one occlusal support zone per side was still maintained (54). Similarly, in another study, lower angulations of the AE were reported in completely edentulous patients compared to subjects in which dental occlusion was still present (53). Interestingly, AEI might suffer modifications even when there is a single missing tooth (32). Thus, decreased AEI were measured in patients with unilateral tooth loss than in the non-missing teeth subjects (32). Furthermore, another study analyzing the unilateral missing-tooth effect on the AEI recorded slightly reduced (but not statistically significant reduced) AEI values on the side of unilateral posterior edentulism compared with the side where all the teeth were present ($P>0.05$) (49). In addition, Hinton described 'more gently sloped' AE in human skeletal samples with molar loss than in specimens with all molars present (41). Interestingly, Granados wrote about the loss of anterior guidance and of cusp height as factors leading to a 'more shallow' AE or even flat in some patients (55). Moreover, Raustia showed that the position of the glenoid fossa was more anterior in edentulous individuals than in dentate ones and even correlated significantly the modifications with the period of time of edentulousness (43). Yet, Unal Erzurumlu and Celenk in 2020 did not find correlations between duration of edentulousness

and values of AE angulation (23). However, there are also few studies that found no statistically significant correlation between tooth loss and flattening of the AE (39,40). Thus, Žabarović *et al* in 2000 measured approximately the same mean AEI values in 59 edentulous dry human skulls and 78 complete dental arches human skull specimens (39) and in a 2006 research no significant variations of AE steepness slope were encountered between dentate and partially edentulous populations (40).

Considering the above presented data and the role of experimental models in scientific research in dental medicine (56-59), we believe that it is necessary to further implement an experimental model of normal TMJ, in relation to which any modification at this level should be evaluated.

8. Conclusions

A wide range of factors seem to influence AEI values. Studies have reported variations in the angles of the slopes of the AE between medieval and recent human dry skulls, as well as between subjects of different racial origin. Recent reports have emphasized the significant role that tooth loss has on the flattening of the AE. Although some articles have described biological sex or age of the subjects as factors which could be associated with AEI variations, edentulism seems to be a significant factor impacting AEI values.

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Availability of data and materials

All information provided in this review is documented by relevant references.

Authors' contributions

MJRV, VN and VRN drafted the manuscript and contributed to data acquisition and study design. DLP, ENB, AP, ADS and RVI participated in the study design and acquisition of data. MJRV, VN and VRN critically revised the manuscript for intellectual content. All authors read and approved the final version of manuscript for publication.

Ethics approval and consent to participate

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Competing interests

The authors declare that they have no competing interests.

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